Simplified volume estimation techniques for contaminated land remediation: a UK example

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Abstract

The need for contaminated land assessment is increasing in the UK as Brownfield sites are being targeted for development. For sites that are deemed to be contaminated, the practical application of a remediation strategy often leads to approximations of volumes of material to be treated. The extent of contamination on the site is assessed based on a limited number of data points within a defined area. At each data point the level of contamination is known for a given sample depth. In the UK a risk based approach is used to determine whether the soil is 'contaminated' and in need of treatment. In a commercial context, time and cost pressures lead to simplifications of the volume estimation process. These simplifications must strike a balance between the environmental risk from underestimates of the contaminated volume and the cost of wasted resources associated with overestimates. This paper presents a comparison between three practical estimation techniques used to assess the volume of 'contaminated' soil on a development site, formerly a gas works. The methods used are; areas of influence, proportional method and interpolation using Kriging. All techniques were found to have a useful application although the limitations of each must be recognised. There is inevitable uncertainty associated with the simplification of any practical situation. In comparing these methods the main uncertainties are identified and management approaches discussed.
Keywords: volume estimation, contaminated soil.

1 Introduction

In the UK the previously developed land (PDL), also referred to as Brownfield land, is being targeted for development. The government have set a target of

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60% of all new housing to be located on Brownfield land [1]. Some of this land has been subject to polluting industrial land uses in the past leading to contamination of the soil. A key information source for assessing contaminated land is site investigation (SI) data, whereby contamination levels are identified at discrete locations through sampling and testing procedures [2,3]. This leads to a series of data points where the level of contamination is known and can be used to determine a representative concentration of contamination across the whole site. In the UK a risk based approach is used to determine whether the level of contamination is acceptable with regard to the risk to human health and the wider environment [4,5]. Should the concentration of contamination on site be found to pose an unacceptable level of risk the site is considered to be "contaminated land", as defined by the regulations [4], and will require some form of remediation.

In the past the most cost effective option for dealing with contaminated material was 'dig and dump' [6]. There are a number of draw backs to this approach including the fact that the problem is simply being relocated and also the availability of landfill is not infinite [7]. The limited availability of landfill has been magnified by legislative changes; most prominently the ban on co-disposal of waste [8]. The subsequent rise in the cost of disposal is leading to an increase in the market for, previously more expensive, process based remediation techniques [9]. The overall increasing cost associated with developing contaminated land drives a need for better delineation of the areas that actually require excavation for treatment or disposal.

The nature of estimation means that there is inevitably some level of uncertainty involved in the assessment process. In the case of contaminated land this is predominately related to the limited amount of information available for the assessment compared with the complexity of the spatial distributions of contamination across the site [10,11]. Part of the solution to improving the estimate of soil volumes is to improve the quality and amount of data available. Several studies into optimised site investigation techniques have been carried out (*e.g.* Demougeot-Renadrd and De Fouquet [12]). However, in a commercial context inevitable cost and time pressures limit the resources available for complex site assessments and collection of additional data.

The aim of this paper is to assess three volume estimation techniques that can be applied to contaminated land where data is limited. The methods used are: areas of influence, proportional method and interpolation using Kriging. Each has been applied to a former gas works case study using different aspects of the data obtained through the SI. The methods have been assessed for their ease of use and appropriateness for the specific site used in the case study.

2 Experimental materials and methods

The volume estimation methods used are:

1. Area of influence: This method is based on the assumption that each data point is representative of the area surrounding it. This method does not consider any spatial relationships between adjacent data points.

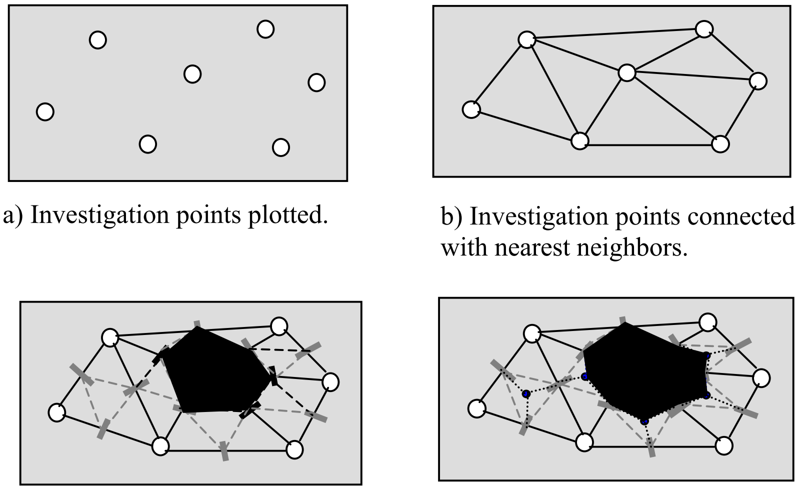
2. Proportional method: Descriptive data from borehole logs is combined with test results to calculate the proportion of each stratum that is likely to be contaminated.
3. Kriging: This method uses the Kriging interpolation method to create contour plots of the contamination distribution across the site. The method is based on an assumed spatial relationship between data points.

Each of the above methods has been applied to a case study, the expected volume of contaminated material calculated and compared.

2.1 Volume estimation method 1: area of influence

This method is based on the assumption that SI data from a specific sampling location can be considered representative of the ground conditions surrounding it. The method uses the spatial distribution of sample points to describe the contamination conditions of site as a whole. The contamination test data for each stratum is used to classify each point as contaminated or not. The method comprises the following steps (Figure 1a to d):

1. Sample points for a given stratum are plotted across the site using a computer aided design package such as AutoCAD [13] (Figure 1a)
2. The data points are connected to their nearest neighbours to produce a series of non-overlapping triangles across the site, similar to the triangular irregular network (TIN) (Figure 1b). To represent ease of application under time pressure the points have been connected by eye only.



a) Investigation points plotted.

b) Investigation points connected with nearest neighbors.

c) Bisect lines between investigation points.

d) Area of influence extended to centroid of remaining areas.

Figure 1: The area of influence method.

3. The mid point of each of these connecting lines is joined to form a polygon around the sample point, creating an area of influence. (Figure 1c)
4. At this point the areas of influence of the sample points do not cover the entire site; the parts of that site that fall between the assigned areas of influence are allocated using the centroid as the intersection point. (Figure 1d)
5. Areas for the outermost data points are extended to the boundary for the site
6. The volume to be treated is calculated multiplying each area by its respective thickness of contaminated material. These volumes are then summed.

2.2 Volume estimation method 2: proportional method

This method is useful for gaining a general overview of the volume of contaminated soil on a site. The proportion of each stratum that is contaminated is estimated based on descriptive borehole logs and contamination test data. The proportion of a stratum that is classed as contaminated is then applied to the total volume of that stratum to calculate a volume of material requiring treatment. The process has the following stages:

1. Collation of borehole data and classification of material as contaminated based on test results. Figure 2 shows an example log with two test points A and B within Material 1. It is assumed that a test result within a given described material is representative of that material. In the example shown two test results within the same description show differing results (A is within acceptable limits and B is not). In this case the test result is applied a depth equidistant to each sample point.
2. Interpretation of material descriptions and classification of untested material. In Figure 2, Material 2 is untested. Should the description of the material be sufficiently similar to Material 1 above that the material can be considered to be the same, the test result of sample B would be considered to be representative of Material 2 also. However, if the descriptions show the material to be different then Material 2 is not classified.
3. Calculation of the total length of contaminated material for each material type, the total recorded length for each material type and subsequently the percentage of each material that is considered contaminated.
    a. All logs that record a given material are summed to give a total recorded length for that material ($\sum L_M$)
    b. The total contaminated length for that material would be calculated for tested data ($\sum L_{TEST}$) and interpreted data ($\sum L_{INTERP}$).
    c. From this, the percent contaminated for a given material can be calculated ($Contam_M$) as shown in Equation (1) below;

$$Contam_M = 100 \times \frac{\sum L_{TEST} + \sum L_{INTERP}}{\sum L_M} \quad (1)$$

4. Apply the percent contaminated for each material type to the total site volume for that material type to calculate volume of contaminated material.

The total material volume is calculated from a three dimensional ground model. This was done by plotting the material thickness recorded at each location and then interpolating, using Kriging, to establish the volume of each material across the whole site. The programme Surfer v8.0 was used as described in Section 2.3 below. The process can be repeated to calculate an uncontaminated volume and an unclassified volume of material for each stratum as required.

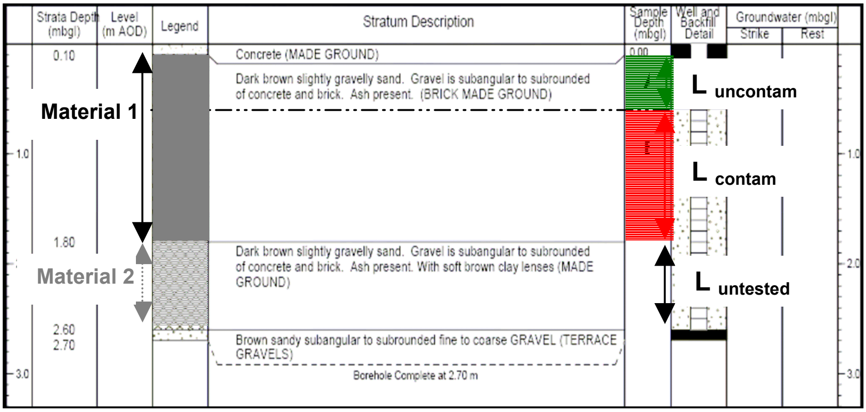


Figure 2: Example borehole log used in the proportional method.

2.3 Volume estimation method 3: Kriging

Surfer v8 [14] was used to carry out this method. Surfer allows data to be plotted and displayed in a number of ways including; data points, contour plots and 3-dimentional surfaces. Multiple maps can be overlain to present different data sets on a single plot. Areas within a surface and volumes between surfaces can be calculated, making the programme ideal for this study. To create a map data points are interpolated to produce regular grid across the area of interest. Ordinary Kriging was selected as the interpolation method for this stud; the default method for the programme. Considered to be the most appropriate as the study is aimed at reproducing simple methods that are likely to be used under time pressures. The Kriging interpolation method is based on the assumption that there is an underlying spatial relationship between data points; i.e. the concentration of contamination varies as a function of the distance between data points. For a full explanation of Kriging refer to Matheron [15] and Matheron and Kleingeld [16].

The process for this method is as follows (repeated each stratum separately):

1. The concentration ratio data is interpolated using Kriging to produce a regular grid of contamination concentrations across the site. This data was then used to produce a contour plot for each contaminant
2. Contour plots for each of the assessed contaminants are overlain to produce a single combined plot indicating areas of contaminated material where concentrations exceed acceptable limits.
3. To assess the depth of affected material Surfer v8 can then be used to plot the total strata thickness and calculate the total site wide volume of each material type.
4. The total areas of contamination exceeding the allowable concentration values are then overlain onto a plot of the thickness of the assessed stratum and the volume of material within these areas calculated.

3 Case study

The site used for the study is in the UK and the location for a proposed housing development. The previous land uses on the site include a former gas works in operation from the late 1800's to 1970 when it was closed. The limited environmental controls in place in the UK during the time that the gas works were in operation lead to polluting operations on the site. Since this time part of the site has remained unoccupied and part has been used as offices and warehouses. It is the vacant portion of the site that is of immediate concern for development and is referred to as Phase 1. The area of the site is approximately 1.1 hectares. SI data has been collected from a series of investigations; the most recent (59 points within Phase 1) has been used for the assessment of contamination with historical information used only for assessing stratigraphy. The site stratigraphy is generally Made Ground (of various types) underlain by alluvial deposits (sandy clay/silt across part of site) and flood plain gravels and sands.

3.1 Contaminants of concern

Based on the results of the initial risk assessment of the site the following contaminants have been identified as posing significant risk to human health, the wider environment or structures on the site. Excavation and remediation or disposal off site is applied to material "contaminated" with respect to the agree remediation targets listed in Table 1 below.

Table 1: Acceptable limits for key contaminants.

Contaminant of concern	Remediation Target (mg/kg)
Ammonium	100
Benzene	8
Naphthalene	23
Bezo(a)pyrene	55

4 Results

For each method described above the volume of material classed as contaminated was calculated for the Made Ground and Alluvial clay layers as the strata of concern for excavation. Table 2 below summarises these results.

Table 2: Calculated volumes.

		Volume of Contaminated Soil		
		Kriging (m^3)	Area of Influence (m^3)	Proportional method (m^3)
Made Ground	*Total Volume*	*14,400*	*11,850*	*14,400*
	Contaminated Volume	5,370	2,585	3,744 (26%)
Alluvium	*Total Volume*	*3,650*	*2,635*	*3,650*
	Contaminated Volume	2,050	880	1,278 (35%)
Total Contaminated Volume		7,420	3,465	5,020

5 Discussion

The application of each method is discussed below followed by a general discussion of common issues.

5.1 Area of influence

The application of the area of influence method is very easy and requires little specialist judgement in its application. The methodology described permits the user to complete a volume calculation based on visual data and can be carried out with the use of readily available software. The method could be improved by more accurately identifying the nearest neighbours when triangulating the data, however this would require another level of sophistication in the software used.

The method may be best used to highlight where more information is required as it incorporates a simple visual plot. If there is a particularly large area of influence attributed to a borehole, it may suggest the need for further investigation. The areas calculated can be compared with the expected hot spot size to indicate whether the SI distribution has been sufficient to find them [17].

The main limitation of the method is that it excludes any spatial relationships between data points. It is also sensitive to data gaps, and uneven sampling distributions across the site. In this case the method consistently predicted the lowest volumes for remediation indicating the SI may be insufficient.

5.2 Proportional method

The application of this method requires much more expert judgement than either of the others. In reading the SI logs the assessor must understand the descriptions and be able to filter the key features that can be used to group materials of a similar nature. For contamination assessment a key challenge is in describing Made Ground and identifying its origin, and associated contamination. The problem is the inherent variability of Made Ground; at the case site seven different types were identified based on contamination test data, material descriptions and colour. Historical maps can be used determine the timing of the placement of the material with respect to site activities, aiding in the classification. As it is impossible to test the whole stratum, the descriptions and history of the material become more important as an indication as to the likelihood of contamination.

The main disadvantage of this method is that it does not identify where the contamination is located, just approximately how much to expect. As such it is really only useful for early design stages and best used in conjunction with some form of plot of test locations.

5.3 Kriging

This method assumes a spatial relationship where one may not always exist, for example ashy patches were found on the case study site, which are isolated hotspots of contamination. Without modification of the Kriging process itself contamination hotspots can become smeared across the site, increasing the affected area. In general this smearing of information may be useful for an overall view of the contamination level of the site; however the delineation of contaminated areas may not represent the variability of the material. In applying contaminated areas to the total thickness of the stratum the method does not consider variation of contamination levels with depth within the stratum. This contributes to overestimated volumes as shown in the case site. This could be improved with more detailed assessment of the thickness of the affected stratum in the calculated volume. On the whole the method is more rigorous as the interpretation process uses all of the available data to predict the location of contamination. The process is most useful for mobile contaminants where there is more of a spatial relationship between data points.

5.4 General discussion

There are a number of general practical issues that need to be considered. For example if a contaminated stratum is overlain by clean stratum the clean stratum may also need to be excavated to assess the contaminated material beneath. In addition the practical issue of ‘over dig’ has not been included. During excavation works on site the difficulties of excavating to the exact base of a strata is accounted for by allowing an additional depth of excavation.

A disadvantage of Kriging and the area of influence methods is that the irregular contaminated areas identified are unlikely to offer a practical remediation plan for the site. In the case of the percent contaminated it is not possible to identify the areas of the site that require remediation at all. All of the methods require care when extrapolating data to the site boundaries. The amount of data available often diminishes at the boundaries and data outside of the boundary is rarely available. The development of these calculations to form a remediation plan would need to allow for these limitations.

With all of these methods there is a need to have a good understanding of the conceptual model for the site, what the nature of the contamination is, where it has come from and the behaviour of the particular contaminants in the ground. With this understanding it is easier to apply an appropriate volume estimation method and subsequently design a practical remediation plan.

6 Conclusions

The methods presented can help to give structure to the volume estimation process. The most appropriate method will depend on the contaminant of concern and its physical and chemical behaviour in the ground. Accepting that, in a commercial context, time and cost pressures mean that problems are simplified by necessity; the issue becomes how to best deal with the associated uncertainty. With all of the methods there is a need to apply an understanding of the chemical behaviour of the contamination, and a practical approach to developing a remediation strategy to be implemented on site.

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References

[1] Office of the Deputy Prime Minister (ODM), Annual Report 2003 (Cm 5906), 2003.
[2] British Standards Institute (BSI), BS5930: 1999 Code of practice for site investigations, BSI: London, ISBN 0 580 33059 1, 1999.
[3] BSI, BS 10175:2001 Code of Practice for the Identification of Potentially Contaminated Land and its Investigation, BSI: London, ISBN 0 580 33090 7, 2001.
[4] ODPM, Environmental Protection Act (Part IIA), HMSO: England, 2000.
[5] Department for Environment, Food and Rural Affairs (Defra), CLR 11: Model Procedures for the Management of Land ODPM: England, 2004.
[6] Rivett, MO, Petts, J, Butler, B and Martin, I, Remediation of contaminated land and groundwater: experience in England and Wales, Journal of Environmental Management, 65 (2002), pp 251–268, 2002.

[7] Wood AA, Contaminated land – an engineers view point. Polluted and Marginal Land 1994, Proceedings of the 3rd International Conference: Re-use of contaminated land and landfills, 1994.
[8] ODPM, Environmental Protection Act England and Wales: The Landfill (England and Wales) (Amendment) Regulations 2004, HMSO: England, 2004.
[9] Market & Business Development Ltd., UK Contaminated Land Treatment Market Development Report 2006, Market & Business Development Ltd: England, 2006.
[10] Demougeot-Renard H, de Fouquet C and Renard P, Heavy Metals in the Environment: Forecasting the Number of Soil Samples Required to Reduce Remediation Cost Uncertainty, Journal of Environmental Quality, 33 (2004), American Society of Agronomy: USA, pp 1694–1702, 2004.
[11] Ramsey, MH and Argyraki A, Estimation of measurement uncertainty from field sampling: the implications for the classification of contaminated land, The Science of the Total Environment, 198 (1997), Elsevier, pp 243–257, 1997.
[12] Demougeot-Renadrd H and De Fouquet C, Geostatistical approach for assessing soil volumes requiring remediation: validation using lead polluted soils underlying a former smelting works, Environmental Science and Technology, 38 (2004), American Chemical Society: USA, pp. 5120–5126, 2004.
[13] AutoDesk, AutoCAD© 2007.
[14] Golden Software Inc. Surfer® Version 8.
[15] Matheron, G, The theory of regionalized variables and its applications, Paris School of Mines publication, pp. 211, 1971.
[16] Matheron, G and Kleingeld, WJ, The evolution of geostatistics, Proceedings of the 20th APCOM International Symposium, SAIMM: Johannesburg, 1987
[17] Department of the Environment (DoE), Contaminated Land Research Report 4: Sampling Strategies for Contaminated Land, DoE: England, 1994.